FULL DEPTH RECLAIMED PAVEMENTS USING CEMENT AND HYDRATED LIME AS STABILIZING AGENTS

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ABSTRACT

Full Depth Reclamation (FDR) is a type of pavement rehabilitation method utilizing Cold-In-Place-Recycling (CIPR), which involves on site recycling and/or remixing of the existing asphalt layer together with a portion of the base layer. The recycled layer consists of reclaimed asphalt pavement (RAP), the existing granular base material and stabilizing agents. Currently, the most commonly used stabilizing agent in Malaysia is Portland cement while the use of hydrated lime is rather scarce mainly due to limited data on its performance. This study analyzes field and laboratory performance of cement and hydrated lime stabilized specimens for various RAP proportions, curing time and moisture variation. The laboratory performance is measured by Indirect Tensile Strength (ITS) test, Unconfined Compressive Strength (UCS) test, and Resilient Modulus test. The results show that the RAP proportion has significant effect on performance of the stabilized specimens. Both cement and hydrated lime stabilized specimens obtain higher compressive strength with less RAP proportions. Higher RAP content samples are also less sensitive to moisture. Cement stabilized specimens showed a generally more superior performance over hydrated lime stabilized specimens. Lime stabilized samples require more curing time over cement stabilized samples to achieve the minimal strengths. However, from the post construction monitoring of up to 36 months, the difference in functional performance between the cement and lime treated sections was observed to be insignificant.

Keywords: Cold in-place recycling, full depth reclamation, pavement preservation, recycling, pavement rehabilitation.

1. INTRODUCTION

a. Full Depth Reclamation

Full Depth Reclamation (FDR), using the Cold-In-Place Recycling (CIPR) technique was first introduced in Malaysia around the mid 80's. Since then, the concept of recycling road pavements as an alternative rehabilitation measure has become popular and acceptable. The technique involves recycling and/or remixing of all the asphalt pavement section and a portion of the underlying materials with an addition of stabilizing agents to produce a stabilized base course. The CIPR technique uses less new materials thereby reduces construction cost by up to 40% over conventional techniques [1].

Although the CIPR technique is gaining acceptance as a cost effective solution in rehabilitating distressed pavement, very little local research has been carried out on its cost effectiveness, design, construction and long term performance. Subsequently, the Public Work Department (PWD) has embarked on a research work in this field, in collaboration with Kumpulan Ikram and Roadcare Sdn. Bhd. The study aims to establish a guideline on the design and construction of CIPR in Malaysia.

b. Stabilizing Agents

In the CIPR process, stabilizing agents are required to increase the performance of the stabilized pavements in terms of strength, durability, and moisture susceptibility [2]. The additive can be chemical or bituminous.

Currently, the most commonly used stabilizing agent in Malaysia is Portland cement. The use of cement in CIPR has proven to minimize rutting and increase in Unconfined Compressive Strength (UCS) of the stabilized layer [3]. Cement, acting as active filler, is also used along with other CIPR stabilizing agents such as foamed bitumen and bitumen emulsion. The addition of cement in foamed bitumen and emulsion has shown to improve the curing time, retained strength and overall strength of the stabilized layer [4].

Lime is also used in CIPR works, however not as often as cement. It is more commonly used to stabilize weak subgrades or soils. Lime is divided into quicklime and hydrated lime, which is processed from quicklime. In soil stabilization, lime is used to remove moisture from the soil and to improve the workability of the soil [5]. Lime treatment of clays soils reduces the shrinkage potential of stabilized soils as the lime-clay reaction results in mineralogical modification of the clay to provide a more moisture stable structure [6].

2. OBJECTIVES

Research works have shown that the performance of the recycled asphalt layer depends on the proportion of reclaimed asphalt pavement (RAP) and the types of stabilizing agents [7]. On site, the amount of RAP, moisture, and aggregate gradation vary from point to point depending on the road condition. These factors, together with the types of stabilizing agents will determine the ultimate performance of the recycled pavement. There is a need to properly understand the behavior of recycled layers in order to facilitate design and construction of recycled pavement and determine their suitability in certain conditions.

This study focuses on the performance of cement and lime stabilized pavement. The main objectives of this study are to:

- Determine the minimum curing time to achieve the desired strength before opening to traffic
- Determine the effect of moisture variation on the strength properties of recycled layer
- Determine the performance of recycled stabilized pavement

3. METHODOLOGY

a. Research brief

This study is divided into 2 parts: laboratory and field performance. The laboratory testing measured the strengths of two parameters, namely curing time and moisture variation, which are significant factors for CIPR works. The strength tests employed were the UCS, Indirect Tensile Strength (ITS), and resilient modulus. The field performance of cement and lime stabilized pavement was measured in terms of their surface conditions.

b. Laboratory Experimental Matrix and Sample Preparation

In order to simulate the performance of CIPR rehabilitated pavement in the laboratory, mixture of different proportions of RAP and crushed stone aggregates (CR) were treated with cement and with lime. These cement and lime treated samples were tested for their strength properties at various curing time and moisture contents. The RAP proportions ranged from 100% RAP to 0% RAP. Table 1 show the experimental matrix used in the study.

Samples for ITS and Resilient Modulus test (100mm briquettes) were prepared in accordance to Marshall method with modifications to the compaction temperature and curing procedures. Samples for UCS test (150mm diameter) were prepared in accordance to Modified Proctor BS 1377.

In order to analyze the effect of curing time on the strength properties, samples were mixed at optimum moisture content (OMC) as determined by the modified Proctor test method (BS 1377). The samples were then dry cured for 1,2,3,7 and 28 days with the cement or lime content being set constant at 3%.

To study the effect of varying moisture content on the strength properties, the cement and lime content was also set constant at 3% and samples were dry cured for 3 days.

Table 1: Experimental Matrix and Sample Quantities for Each Sample Types

Aggregate Proportion	Strength Test	Curing Time (Day)					Moisture Content (%)*				
		1	2	3	7	28	-30	-15	omc	+15	+30
		Sample Quantities									
100% RAP	UCS	3	3	3	3	3	3	3	3	3	3
	ITS	3	3	3	3	3	3	3	3	3	3
	R.Modulus	3	3	3	3	3	3	3	3	3	3
75% RAP + 25% CR	UCS	3	3	3	3	3	3	3	3	3	3
	ITS	3	3	3	3	3	3	3	3	3	3
	R.Modulus	3	3	3	3	3	3	3	3	3	3
50% RAP + 50% CR	UCS	3	3	3	3	3	3	3	3	3	3
	ITS	3	3	3	3	3	3	3	3	3	3
	R.Modulus	3	3	3	3	3	3	3	3	3	3
25% RAP + 75% CR	UCS	3	3	3	3	3	3	3	3	3	3
	ITS	3	3	3	3	3	3	3	3	3	3
	R.Modulus	3	3	3	3	3	3	3	3	3	3
100% CR	UCS	3	3	3	3	3	3	3	3	3	3
	ITS	3	3	3	3	3	3	3	3	3	3
	R.Modulus	3	3	3	3	3	3	3	3	3	3

*Note: Moisture variation ranged from +30% of OMC to -30% of OMC

c. Description of Materials

Table 2 shows the grading, OMC, maximum dry density (MDD), cement/lime content of the samples for each RAP proportions. The cement/lime content used in this study is based on the current practice in Malaysia.

Table 2: Material gradation, OMC, MDD, Cement/Lime content

Grading Sieve Size (mm)	Aggregate Proportion (% Passing)				
	100% RAP	75%RAP + 25%CR	50%RAP + 50%CR	25%RAP + 75%CR	100%CR
50	100	100	100	100	100
37.5	100	99.5	99	98.5	97
20	93.8	89.5	85.5	82	78
10	71	69	66	63	60
5	45.3	45	45	45	45
2.36	26.4	28	29	31	32.11
0.425	2.2	7	9.5	12	13.71
0.075	0.4	3	4.5	5	6.91
OMC (%)	4.81	5.14	5.82	6.08	6.13
MDD (Mg/m³)	1.879	2.024	2.161	2.281	2.253
Cement/Lime Content (%)	3	3	3	3	3

These gradations were adopted based on the typical gradations normally observed in actual construction. For example the gradation for 100% RAP would be different from the gradation of FDR works using 50% RAP. The OMC and MDD for each gradation were determined before the addition of cement or lime. In practice the cement or lime content must be designed to the required strength based on the REAM Specifications for Cold-In Place- Recycling. However for this study, in order to analyze the effect of curing time, moisture variation and RAP proportion, the cement/lime content is set constant at 3% for all samples. This percentage was found to be the percentage normally obtained when designing for CIPR works that uses cement as stabilizing agent. Since lime is rarely used as stabilizing agent, the value of 3% was also adopted for cost control reason.

a. Field Study

For this study, four (4) research sites, each comprised of 1km single carriageway road were monitored in terms of crack type, severity and extent of cracks, as well as rut depth. Each site is further divided into four (4) 200m stabilized sections, using different stabilizing agents namely foamed bitumen, bitumen emulsion, cement, and lime. However the foamed bitumen, and bitumen emulsion stabilized sections are not included in the scope of this paper. A control section of 200m length was also constructed using the conventional pavement rehabilitation method of removing the existing asphalt and base layer, and replacing them with new crusher run and asphalt layer.

Each section was designed to have the same structural strength and to withstand the same loading, and to last the same number of years. The structural pavement design utilizes the mechanistic-empirical design method with the use of Shell fatigue and rutting transfer functions. The strength of the stabilized CIPR layer of both stabilizing agent was assumed to have a resilient modulus of 1350MPa. Each stabilized layer were covered with asphaltic binder and wearing course. All sections were designed to last seven (7) years. The time after rehabilitation and the traffic loading for each research site is shown in Table 3.

Table 3: Research site details

Site	Years after construction	Traffic Loading
FT190	3 years	High (36msa)
FT14	3 years	Medium (19msa)
FT1739	2 years	Low (4msa)
FT126	2 years	Low (4msa)

4. RESULTS AND ANALYSIS

a. Laboratory Test Results

<u>Curing Time</u>

Curing time is critical for CIPR works. Unlike other rehabilitation techniques, CIPR pavement cannot be immediately opened to traffic once it is completed. The reclaimed materials that have been stabilized needs to be properly cured to achieve the minimum strengths to prevent ravelling under vehicle traffic [2]. In Malaysia, the Public Works Department (PWD) requires the bituminous overlay to be carried out 3 days after recycling works is completed.

<u>UCS vs Curing Time</u>

The cement and lime treated samples were tested for compressive strength at different curing period using the UCS test. For both cement and lime treated samples the UCS strength increases with curing time for all proportions. At 3 days curing time until 28 days curing time the 100% crusher run samples were shown to have the highest UCS values. The 100% RAP samples were shown to have the lowest UCS values for all curing time. Generally, the UCS values decreases with higher percentage of RAP.

Overall the cement treated samples achieved higher UCS values over lime treated samples for all RAP proportions, particularly for lower RAP content. At 3 days curing, cement treated samples with 75% and 100% RAP did not achieve the minimum UCS strength of 2Mpa. For the 75% RAP a minimum curing period of 12 days was required while for the 100% RAP failed to achieve the minimum strength even after 28 days. For lime treated samples the UCS strength did not exceed 2MPa even after 28 days of curing, except for the 25%RAP and 0%RAP samples. For higher RAP proportions, a higher cement/lime content and/or longer curing period may be required to satisfy the minimum strength. The graph of UCS vs curing time is shown in Figure 1.

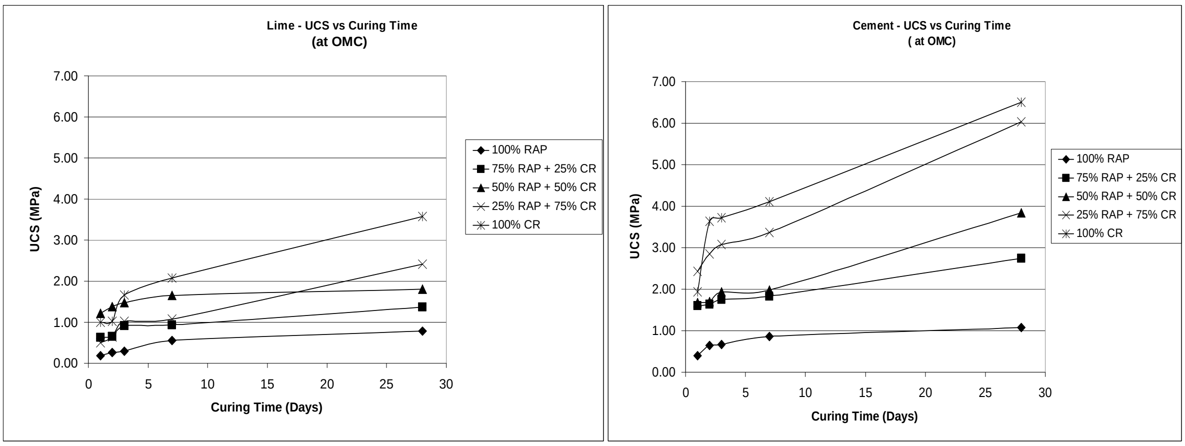

Figure 1: UCS vs Curing Time

<u>ITS vs Curing Time</u>

For both cement and lime stabilized samples the ITS strength increases with curing time for all proportions. Samples with 75% RAP was shown to have the highest strength at 28 days of curing. At 3 days curing time, lime treated samples of all RAP proportions did not achieve the minimum strength of 2Mpa while all cement treated samples achieved the required strength.

The cement treated samples for all RAP proportions also show higher ITS values over the lime treated samples at the same curing time. Subject to cost comparison, cement is therefore preferred as the stabilizing agent for CIPR works. The graph of ITS vs curing time is shown in Figure 2.

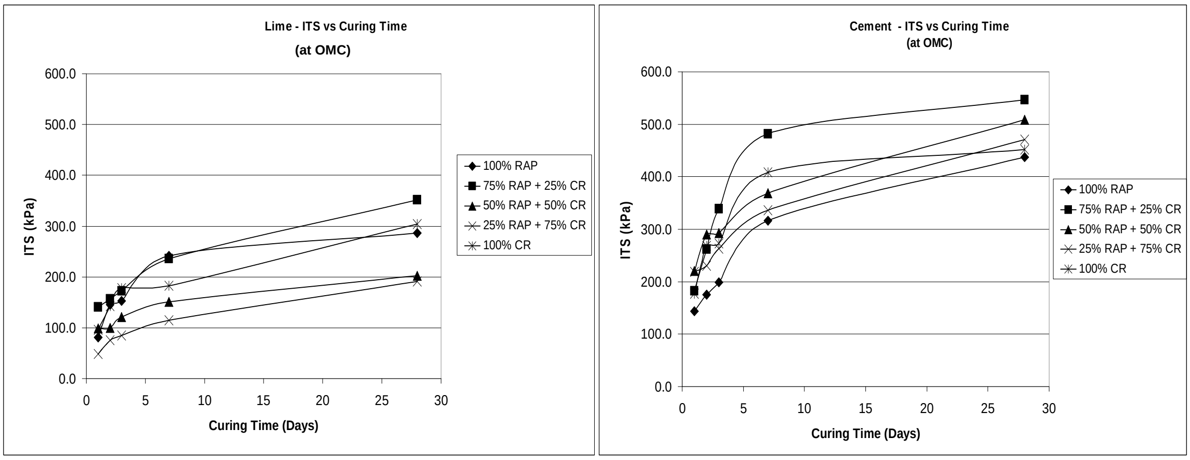

Figure 2: ITS vs Curing Time

Resilient Modulus vs Curing Time

For both cement and lime, the resilient modulus increases with curing time and the 0% RAP samples were shown to have the highest resilient modulus strength for all curing time.

The cement treated samples were found to achieve the required modulus of 1350Mpa faster than the lime treated samples. (A resilient modulus value of 1350MPa is assumed when designing pavement structure). After 3 days curing, all cement treated samples achieved the desired design resilient modulus of 1350MPa. However the lime treated samples did not achieved the design value within that period except for the 75% and 0% RAP samples. The results indicate that the use of lesser amount of cement is possible to achieve the design modulus or alternatively a higher modulus can be assumed when cement stabilized layer is adopted. The graph of resilient modulus vs curing time is shown in Figure 3.

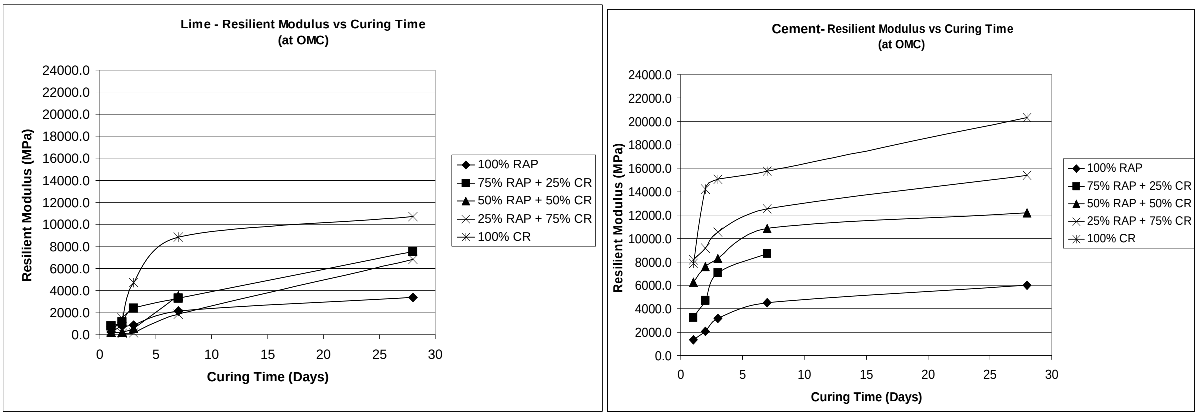

Figure 3: Resilient Modulus vs Curing Time

Based on the above, cement treated samples have shown better performance than lime treated samples as they needed shorter curing time to achieve the required strength. It can be concluded that CIPR works, using 3% cement as stabilizer and with not more than 50% RAP, could be opened to traffic after 3 days because they satisfy the minimum required strengths. However the stabilized samples with 3% lime did not achieve the minimum strength after 3 days of curing, for all RAP proportions. It is therefore advisable that lime stabilization at 3% and using not more than 25% RAP, should only be opened to traffic after 28 days. For practical reasons, this treatment may only be suitable for rural low volume roads or gravel roads. In addition, the laboratory results showed that for all RAP proportions, the inclusion of 3% lime is not sufficient to fulfill the various minimum strengths requirement. The appropriate quantity of lime to be incorporated in the field works should therefore be determined during the mix design process using the actual field materials to be recycled. The assumed modulus value of 1350Mpa is well achieved when 3% cement is used in the mix design.

Moisture Content

The correct moisture or fluid content is critical in achieving adequate compaction with minimum effort [1]. The effects of moisture content variation on the strength properties of lime and cement treated samples is analyzed using the UCS, ITS, and resilient modulus.

UCS vs Moisture Content

When testing UCS against various moisture contents, it was found that the maximum UCS values for both cement and lime stabilized samples did not occur at OMC, except for samples with 25% RAP proportion. For instance, the 0% RAP cement treated samples and 50% RAP lime treated samples achieved maximum UCS at -15% from OMC.

It was also observed that for both cement and lime stabilized samples with higher RAP proportions, the variation in moisture content did not affect the UCS values significantly. As an example, the UCS values for cement treated samples with 100% RAP ranged only from 0.4 MPa to 0.6 MPa whereas samples with 0% RAP ranged from a low point of 2.2MPA to 4.6 MPa. The variation in RAP proportion also affected the UCS values more significantly at moisture contents lower than the OMC. The UCS values were also generally lower at higher moisture content for all RAP proportions.

For lime stabilized samples, all except 0% RAP, did not achieve the minimum UCS of 2MPa within the +-30% moisture variation at three (3) days curing time. The graph of UCS vs moisture variation is shown in Figure 4.

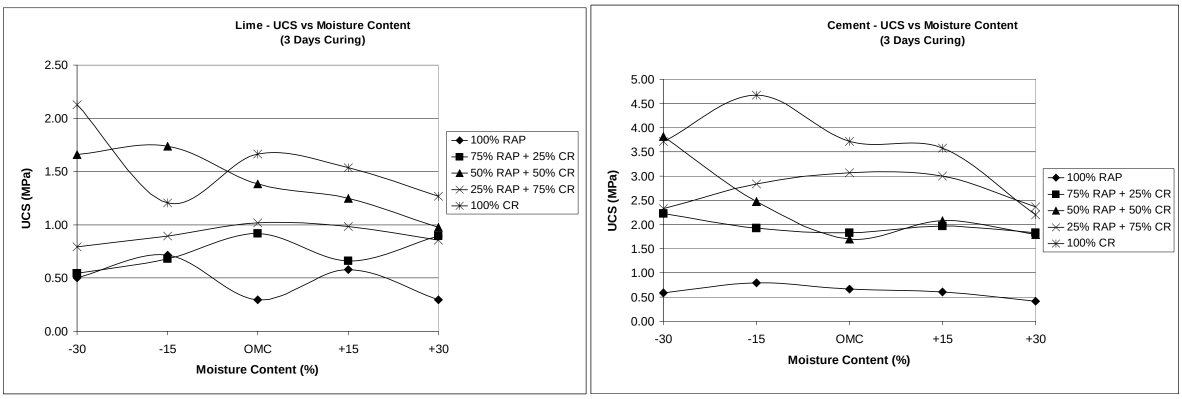

Figure 4 : UCS vs Moisture Variation

ITS vs Moisture Content

For both cement and lime treated samples, the highest ITS values did not occur at OMC. Similar to UCS results, both cement and lime treated samples with higher RAP content were less sensitive to moisture content variation.

All lime treated samples did not attain the minimum required strength of 200kPa. At moisture content +30% of OMC, the cement treated samples with 100%, 50% and 25% RAP did not achieve 200kPa. The graph of ITS vs moisture content is shown in **Figure 5**.

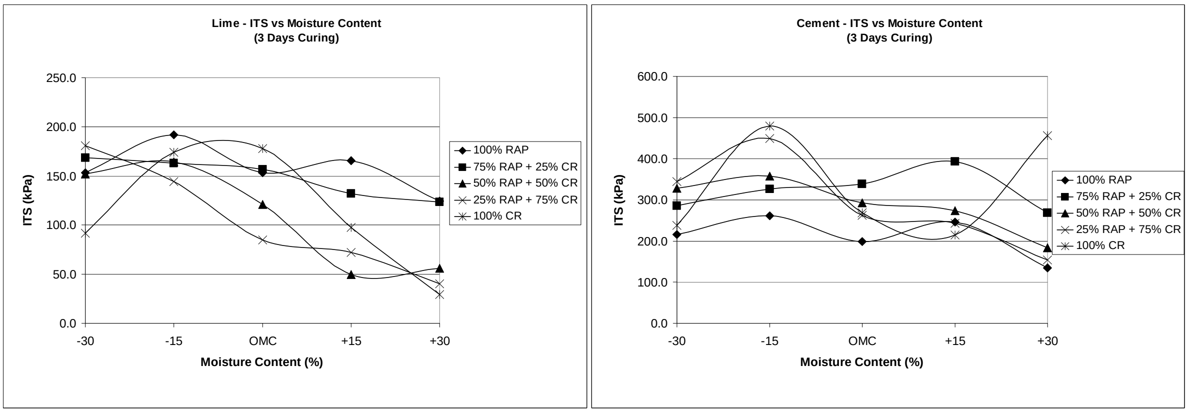

Figure 5 : ITS vs Moisture Variation

<u>Resilient modulus vs Moisture Content</u>

As with UCS and ITS, the resilient modulus for both cement and lime treated samples generally peaked at moisture contents lower than the OMC. The results also showed that samples with higher RAP contents were less sensitive to moisture variation. For both treatments, the maximum resilient moduli were recorded at 0% RAP. The cement treated samples showed a significantly higher resilient modulus compared to the lime treated samples. The graph of resilient modulus vs moisture content is shown in **Figure 6**.

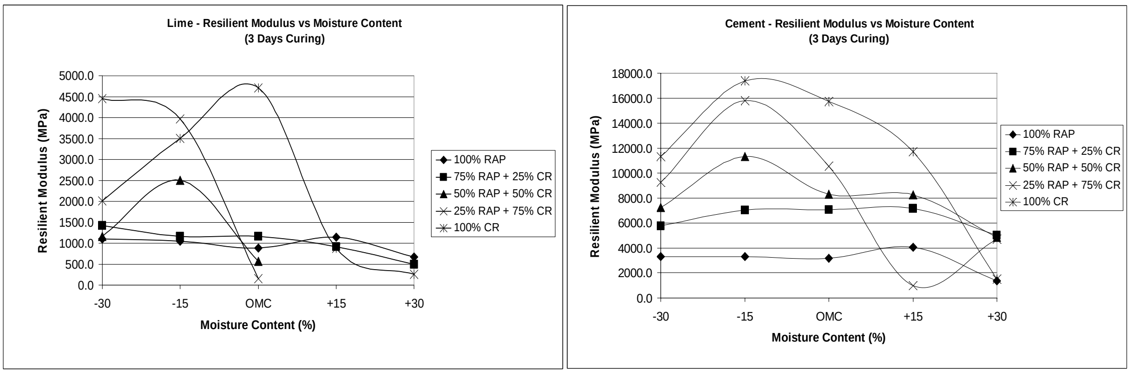

Figure 6 : Resilient Modulus vs Moisture Variation

b. Field Performance Study

For the four sites, UCS tests were carried out as part of the mix design process. Table 4 shows the UCS values at seven (7) days for both cement and lime treated sections. For each site equal amount of cement and lime were used to stabilize the respective sections. The RAP proportions for all sites were 80%. The resilient modulus and ITS tests were not carried out for these sites.

Table 4: Research site UCS values

Site	UCS (MPa)	
	Cement	Lime
FT190	2.3	1.9
FT14	2.3	2.3
FT1739	2.1	1.1
FT126	2.9	2.15

It should be noted that the lime treated sections for two of the sites did not meet the minimum strength of 2MPa at seven (7) days.

Surface condition survey in terms of cracking and rutting was carried out to investigate the relationship between laboratory and field performance.

Cracking

The control sections were shown to have the most severe and extensive cracks among the three rehabilitation types. For the control sections cracks were found on 3 out of 4 sites. The cracking for the cement and lime were found to be relatively similar. The summary of cracks on the research sites is shown in Table 5.

Table 5: Cracking on Research sites

Sites	Crack Type			Percentage of Cracks (%)		
	Cement	Lime	Control	Cement	Lime	Control
FT190	Crocodile Cracks	Crocodile Cracks	Crocodile Cracks	29	31	83
FT14	No Cracks	No Crack	Crocodile Cracks	0	0	29
FT1739	More than one crack	No Crack	No Cracks	1	0	0
FT126	Interconnected Cracks	No crack	Interconnected Cracks	1	0	9

Rutting

Similar to cracking, rutting was also shown to be more severe on the control section with rut depths of 30mm or higher on 2 of the 4 research sites. For the lime stabilized sections, one section has a localized rut depth of 20mm. The summary of rutting on the research site is shown in Table 6.

Table 6: Rutting on Research site

Site	Maximum Rutting (mm)		
	Cement	Lime	Control
FT190	0	20*	30
FT14	0	0	0
FT1739	0	0	0
FT126	0	0	40

*Localized Rutting

Based on the surface condition survey of the field research section, the CIPR sections performed significantly better than the control section. Both the cement and lime treated sections were found to perform equally.

5. CONCLUSION

CIPR works with 50% or less RAP content stabilized using 3% cement satisfied the required minimum strength at 3 days curing time. After the 3 days of curing, the samples achieved the desired UCS of 2.0 MPa, and ITS of 200Kpa. It also exceeds the resilient modulus design assumptions of 1350MPa. However, samples treated with 3% lime did not attain the minimum strength at 3 days. For the 25% RAP the minimum curing time to achieve the required strength is 28 days while for 0% RAP a curing time of 10 days is found to be sufficient.

The maximum strength for both cement and lime treated samples generally occurred at moisture contents lower than the OMC. Moisture variation was also found to have insignificant effects on the strength of samples with high RAP content.

In general, based on laboratory results, cement was found to perform better than lime as a stabilizing agent. At any given moisture content, it requires shorter curing period to achieve similar strength and yields relatively higher modulus values compared to lime.

From the survey of the research site, it was found that cement and lime stabilized sections performed much better compared to the conventionally rehabilitated sections. Up to 36 months of post-monitoring, the cement and lime sections were found to be performing equally well. This suggests that both recycled layers exhibited similar strength after this period. This is despite the laboratory findings which showed that cement stabilized samples performed better than that of lime. However this assumption needs to be confirmed by analyzing the modulus values of those layers using the back calculation technique.

In conclusion both cement and lime are suitable stabilizing agents for recycling works. Although similar performances have been exhibited by both cement and lime stabilized sections, cement is currently preferred as it satisfies all the laboratory tests requirements.

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